Joseph Black, M.D.

A Discourse

By
Sir William Ramsay, K.C.B., F.R.S.

*Delivered in the University of Glasgow
on Commemoration Day,
19th April*, 1904

Glasgow
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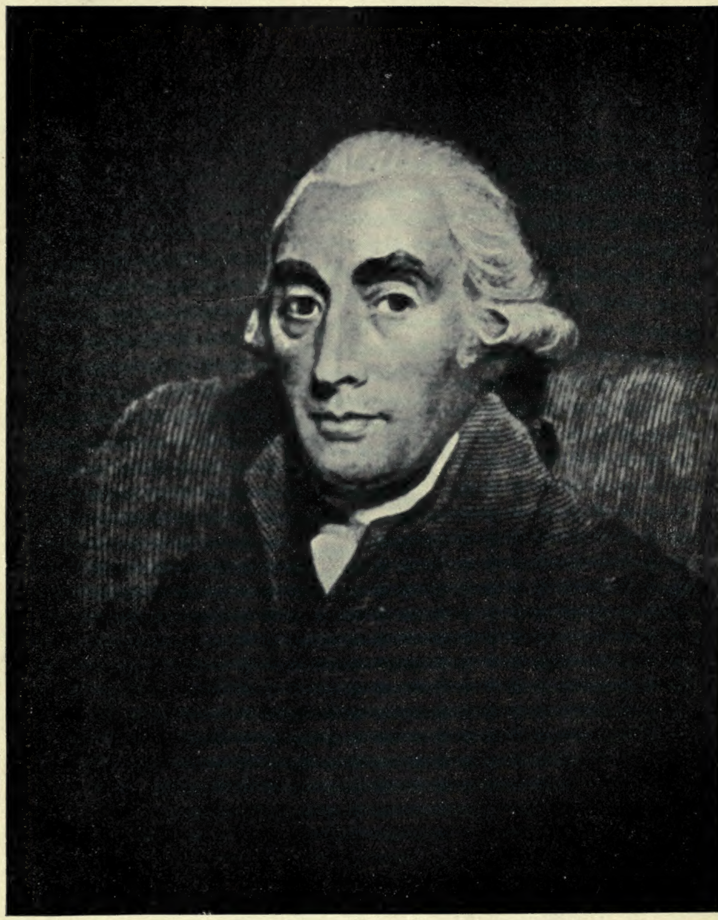

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BLACK: HIS LIFE AND WORK.

THERE are some natures so happily constituted that they escape many of the trials which beset most men. Marcus Aurelius thanked his adopted father for having taught him the advantages of "a smooth and inoffensive temper; constancy to friends, without tiring or fondness; being always satisfied and cheerful; reaching forward into the future, and managing accordingly; not neglecting the least concerns, but all without hurry, or being embarrassed." Such a character had Joseph Black. Dr. Robison, the editor of his lectures, his successor here, and his biographer, wrote: "As he advanced in years, his countenance continued to preserve that pleasing expression of inward satisfaction, which, by giving ease to the beholder, never fails to please. His manner was perfectly easy and unaffected, and graceful. He was of most easy approach, affable, and readily entered into conversation, whether serious or trivial. His mind being abundantly furnished with matter, his conversation was at all times pertinent and agreeable. He was a stranger to none of the elegant accomplishments of life." His friend Dr. Ferguson said of him: "As Dr. Black had never anything for ostentation, he was at all times precisely what the occasion required, and no more. Never did anyone see Dr. Black

hurried at one time to recover matter which had been improperly neglected on a former occasion. Everything being done in its proper season and place, he ever seemed to have leisure in store; and he was ready to receive his friend or acquaintance, and to take his part with cheerfulness in any conversation that occurred." His successor, Dr. Thomas Thomson, found Dr. Robison's estimate of Black's character so just that he appropriated it almost verbatim in his *History of Chemistry* without the formality of quotation marks.

His pupil, Henry Brougham, one of the founders of the college in which I have the honour to hold a Chair, portrays him in his *Philosophers of the time of George III.* as "a person whose opinions on every subject were marked by calmness and sagacity, wholly free from both passion and prejudice, while affectation was only known to him from the comedies he might have read. His temper in all the circumstances of life was unruffled. . . . The soundness of his judgment on all matters, whether of literature or of a more ordinary description, was described by Adam Smith, who said, he 'had less nonsense in his head than any man living.'" Brougham, writing as an old man, said: "I love to linger over these recollections, and to dwell on the delight which I well remember thrilled me as I heard this illustrious sage detail the steps by which he made his discoveries, illustrating them with anecdotes sometimes recalled to his mind by the passages of the moment, and giving them demonstration by performing before us the many experiments which had revealed to him first the most important secrets of nature. Next to the delight of having actually stood by him when his victory was gained,

we found the exquisite gratification of hearing him simply, most gracefully, in the calm spirit of philosophy, with the most perfect modesty, recount his difficulties, and how they were overcome ; open to us the steps by which he had successfully advanced from one part to another of his brilliant course ; go over the same ground, as it were, in our presence, which he had for the first time trod so many long years before ; hold up perhaps the very instruments he had then used, and act over again the same part before our eyes which had laid the deep and broad foundations of his imperishable renown. Not a little of this extreme interest certainly belonged to the accident that he had so long survived the period of his success—that we knew there sat in our presence the man now in his old age reposing under the laurels won in his early youth. But take it altogether, the effect was such as cannot well be conceived. I have heard the greatest understandings of the age giving forth their efforts in its most eloquent tongues—have heard the commanding periods of Pitt's majestic oratory—the vehemence of Fox's burning declamation—have followed the close compacted chain of Grant's pure reasoning—been carried away by the mingled fancy, epigram and argumentation of Plunket ; but I should without hesitation prefer, for mere intellectual gratification (though aware how much of it is derived from association) to be once more allowed the privilege which I in those days enjoyed of being present while the first philosopher of his age was the historian of his own discoveries, and be an eyewitness of those experiments by which he had formerly made them, once more performed with his own hands."

Truly, Scotland in the last half of the eighteenth

century was the home of many great men. Adam Smith, the first political economist; David Hume, the historian; James Hutton, the geologist; and James Watt, the engineer: all these were intimate friends of Black's, and each in his way was an originator of the first order. And it is my pleasant task to-day to present to you an account of Black's discoveries and their consequences, and to attempt to show that his work began a new epoch for chemistry and physics.

There is little to tell of Black's early history; nor, indeed, was his life even remotely adventurous. His career may be told in a few words:

Joseph Black was born on the banks of the Garonne, near Bordeaux, in 1728. His father, John Black, was a native of Belfast, descended from a Scottish family which had settled there; he resided at Bordeaux, where he carried on a business in wine; he was an intimate friend of President Montesquieu. Joseph was one of thirteen children, of whom eight were sons. In 1740, at the age of twelve, he was sent to school in Belfast; and like many other boys of the north of Ireland, he crossed to Glasgow to attend this College, for in those days, of course, the Queen's College had not been founded. This was in the year 1746. Dr. Robison mentions letters from Mr. Black to his son Joseph, from which it would appear that he was in every respect a satisfactory son and a diligent student. He received a general education; we find, at least, that he could write good Latin; and he was taught ethics by Adam Smith. His leanings for natural science, however, were probably encouraged by his intimate friendship with the son of the Professor of Natural Philosophy, Dr. Robert Dick, later successor to

his father in the chair, who, unfortunately, occupied it only a few years, for he was early cut off by death. Black also owed much to Cullen, of whom a very interesting account is given by Thomas Thomson in his *History*. Cullen was Lecturer in Chemistry in this University from 1746 to 1756; and in 1751 he was appointed Professor of Medicine; at that time, and, indeed, until Thomas Thomson taught chemistry, that subject was taught only by a lecturer. Thomson attributes to him a singular talent for arrangement, distinctness of enunciation, vivacity of manner, and profound knowledge of his science—in short, enthusiasm—qualities which made him adored by his students. He took especial pains to gain their friendship by frequent social intercourse with them, and no doubt early recognised Black's great promise. Cullen's single contribution to chemico-physical literature dealt with the boiling of ether on the reduction of pressure, and its growing cold during the process. The reason of this behaviour, however, was later discovered by Black, for Cullen confined himself to recording the observation. It was not long before Black rendered help to Cullen as his assistant; and Black's name was frequently quoted by Cullen in his lectures as an authority for certain facts.

Black's methodical habits led him to keep a sort of common-place book, in which not merely the results of his experimental work was entered, but also notes on medicine, jurisprudence, or matters of taste; and he practised "double entry," for he also kept separate journals in which these notes were distributed according to their subjects. From these note-books the dates of his most important discoveries can be traced.

Chemistry, in these days, was handmaid to medicine; the influence of the iatro-chemists, founded by Paracelsus, still held its sway, although certain bold investigators—among them Boyle, Mayow, and Hales—a century before, had shaken themselves free from its thraldom. And the lectureship on chemistry in Glasgow was regarded as a step to a more remunerative position, and was held, along with the Crown professorship of medicine, by Cullen from 1751 to 1756. It was probably owing to Cullen's advice that Black went to Edinburgh in 1750 or 1751 to finish his medical studies; perhaps another reason may be found in his having had a cousin in the University, Mr. James Russel, as Professor of Natural Philosophy, with whom he lived. There he took the degree of doctor of medicine in 1754. It is true that he might have graduated in Glasgow three years earlier; but no doubt his thoroughness made him wish to offer a thesis worthy of praise, and it was this thesis which established his reputation. More of this hereafter.

In 1756 Dr. Cullen was called to fill the Chair of Chemistry in Edinburgh, and Black, who had been practising as a physician since he had graduated, was called to succeed him in the Chair of Anatomy and the lectureship in Chemistry; for his reputation in the subject which he had made his own was even then a high one. Black did not retain the Chair of Anatomy for long, however; his tastes lay more in the direction of medicine; and with the concurrence of the University he and the professor of medicine exchanged chairs. While he held these offices, he also engaged in medical practice; and Robison says that his countenance at

that time of life—he was then about 32—was equally engaging as his manners were attractive; and in the general popularity of his character he was in particular a favourite with the ladies. No one, so far as we know, was singled out by his preference; and to the end of his days he remained unmarried. It appears that the ladies regarded themselves as honoured by his attentions, and we are told that these attentions were not indiscriminately bestowed, but exclusively on those who evinced a superiority in mental accomplishments or propriety of demeanour, and in grace and elegance of manners.

In 1766, Dr. Cullen exchanged the Chair of Chemistry at Edinburgh for that of Medicine; and with one accord University and town united in calling Dr. Black to the vacant chair. Indeed, in 1756, he had been recommended for the chair by the University; but the Town Councillors who were the electors did not agree with the recommendation, and Cullen was appointed. Now, however, unanimity prevailed, and Black removed to Edinburgh, where he spent the rest of his days.

From this date, he devoted himself to tuition, and spared no pains to make his lectures attractive and useful. He illustrated them by numerous experiments; Robison tells us that, "while he scorned the quackery of a showman, the simplicity, neatness, and elegance with which they were performed were truly admirable." And Brougham also praises his manipulation. "I have seen him," he writes, "pour boiling water or boiling acid from one vessel to another, from a vessel that had no spout into a tube, holding it at such a distance as made the stream's diameter small, and so vertical that not a

drop was spilt." "The long table on which the different processes had been carried on was as clean at the end of the lecture as it had been before the apparatus was planted upon it. Not a drop of liquid, not a grain of dust remained."

Black had a profound influence on the attitude of the Edinburgh public towards science. The reputation which he established as a lecturer induced many to attend his lectures without any particular wish to learn chemistry, but merely to enjoy an intellectual treat; and it became the fashion to hear him.

The study of the chemistry of gases, after Black's discovery of carbonic acid, made rapid progress; but Black did not take part in its advance. His health had never been good; he was very subject to dyspepsia, and on several occasions his lungs or his bronchiae appear to have narrowly escaped being affected, for he was troubled with spitting of blood. But he had learned the lesson—*γνῶθε σεαῦτον*—know thyself; and he regulated his exercise and his diet with the result that he lived a quiet, and a fairly long life. "Happy is the nation that has no history"; and Dr. Black's uneventful life was passed in happiness. He held his chair for more than thirty years, and grew old gracefully, living amongst many intimate friends. He at one time acquired a reputation for parsimony; but Brougham, while suggesting a reason for this report, namely that he kept a pair of scales on his study table with which he used to weigh the guineas paid in as fees, defends this perhaps somewhat curious practice, and refutes the imputation; and Robison, who also alludes to it, states in a footnote that he could give more than one or two

instances in which a great part of Black's fortune was at risk for a friend.

As his strength decreased, the care of his health occupied more and more of his attention; he became more and more abstemious in his diet. One of his intimate friends, Dr. Ferguson, gives the following account of his death, one worthy of such a calm and placid philosopher: "On the 26th November, 1799, and in the seventy-first year of his age, he expired, without any convulsion, shock, or stupor to announce or retard the approach of death. Being at table, with his usual fare, some bread, a few prunes, and a measured quantity of milk, diluted with water, and having the cup in his hand when the last stroke of his pulse was to be given, he had set it down on his knees, which were joined together, and kept it steady with his hand in the manner of a person perfectly at ease, and in this attitude expired, without spilling a drop, and without a writhe in his countenance, as if an experiment had been required to show his friends the facility with which he departed."

He left more money than anyone thought he could have acquired in the course of his career. His will was a somewhat fantastic one; he divided his property into ten thousand shares; and he distributed it among numerous individuals in shares or in fractions of shares, according to his conception of their needs or deserts.

A tale is told in *Kay's Portraits* of Black and Hutton, who were almost inseparable cronies. Having had a disquisition as to the waste of food, it occurred to them that while testaceous marine animals were much esteemed as an article of diet, while those of the land were

neglected, they resolved to put their views in practice, and having collected a number of snails, had them cooked, and sat down to the banquet. Each began to eat very gingerly; neither liked to confess his true feelings to the other. "Dr. Black at length broke the ice, but in a delicate manner, as if to sound the opinion of his messmate: 'Doctor,' he said, in his precise and quiet manner, 'Doctor, do you not think that they taste a little—a very little queer?'—'queer,—queer indeed!—tak them awa', tak them awa'!' vociferated Dr. Hutton, starting up from table, and giving vent to his feelings of abhorrence."

To see a portrait of the subject of a biography is a great help towards realising this character: and the likenesses which are here presented reveal, I think, Black as a calm, contemplative nature; but Kay's caricatures indicate that he could take a somewhat humorous view of life, and perhaps might even display a vein of caustic sarcasm. The portrait of him lecturing may well have been sketched, we may suppose, while he was making scathing comments on the objections raised by a German chemist named Meyer to his doctrine of causticity, which "that person," as Brougham tells us, "explained by supposing an acid, called by him *acidum pingue*, to be the cause of alkaline mildness. The unsparing severity of the lecture in which Black exposed the ignorance and dogmatism of this foolish reasoner cannot well be forgotten by his hearers." It appears to me, however, that Meyer's theory cannot have been correctly stated by Brougham (for it is remarkably like Black's own explanation), or must have been misunderstood by Black. Another of Kay's portraits exhibits Black and

"The Philosophers"—Hutton and Black.

From John Kay's Caricatures.

Hutton, under the title of "The Philosophers"; and here again the caricaturist has made it obvious that Black could appreciate a joke. A third portrait represents him taking a gentle walk; it conveys an idea of his appearance in his fifty-ninth year.

The portrait of Dr. Cullen, Black's predecessor both in Glasgow and Edinburgh, and his life-long friend, is also reproduced. Cullen died in 1790, at the age of 81.

In the olden days it was considered quite as marvellous that a gas could be made to occupy a small volume, or that "air" could be produced in quantity from a stone, as that an Arabian "djinn" of enormous size and ferocious mien could issue from a bottle, as related in the "Tale of a Fisherman," one of the charming stories of the *Arabian Nights' Entertainments.* It is true that in the middle of the seventeenth century Robert Boyle had enunciated his famous discovery, "Touching the Spring of the Air"; in which he proved that the greater the pressure to which a gas is exposed the smaller the volume it will occupy. But however great the pressure, Boyle's air remained air. It might have been thought that the boiling of water into steam should have convinced men that a liquid, at least, could be changed into a gas; but the fact that steam changed back to water probably prevented attention being paid to its comparative large volume while hot. It was Black's discovery of the production of carbonic acid gas from marble, or as he named it, "fixed air," which first directed notice to this possibility of the production of a gas from a solid; and further, the peculiar property of this gas—its power of being fixed—was one which

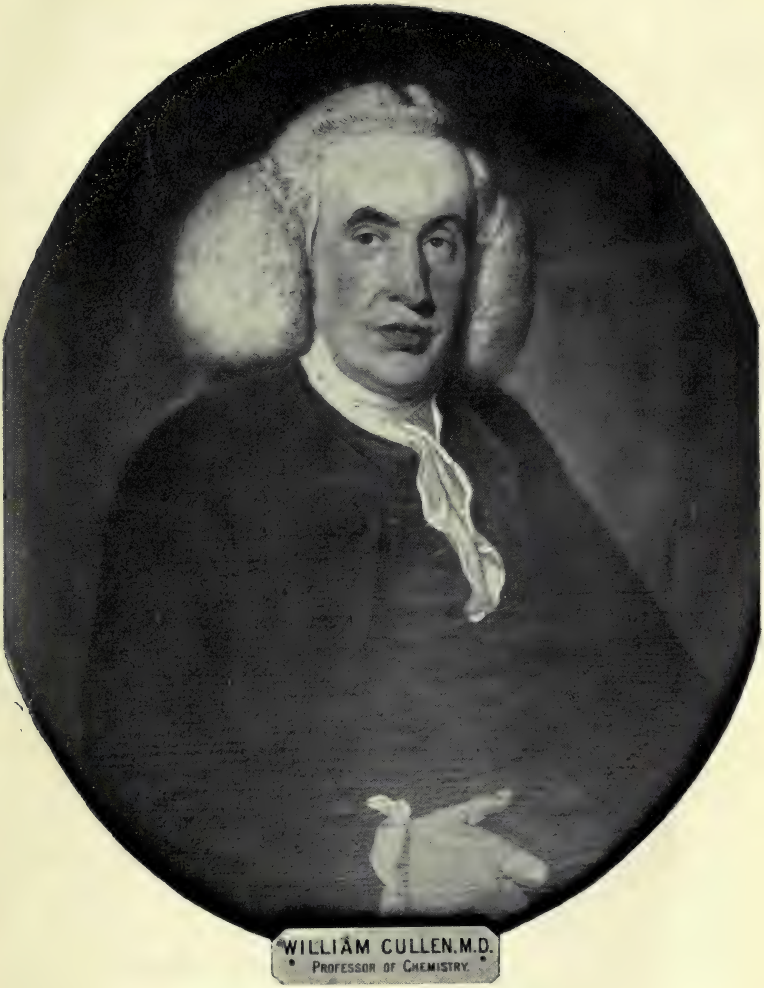
completely differentiated it from ordinary air. Stephen Hales, the botanist, it is true, had distilled many substances of vegetable, animal and mineral origin; among them he treated many which must have produced impure hydrogen, marsh-gas, carbonic acid gas, and oxygen; but Hales contented himself with measuring the volume of gases obtained from a known weight of material, without concerning himself as to their properties. And as the result of many experiments, he concluded that "our atmosphere is a *chaos*, consisting not only of elastick, but also of unelastick air-particles, which in plenty float in it, as well as the sulphureous, saline, watry, and earthy particles, which are no ways capable of being thrown off into a permanently elastick state, like those particles which constitute true permanent air." This was the current belief as regards the nature of air.

The cause which gave rise to Black's famous research is a curious one. Sir Robert Walpole, as well as his brother Horace, afterwards Lord Walpole, were troubled with the stone. They imagined that they had received benefit from a medicine invented by a Mrs. Joanna Stephens; and through their influence she received five thousand pounds for revealing the secret, which was published in the *London Gazette* on the 19th June, 1739. It was described as follows:

"My medicines are a Powder, a Decoction, and Pills. The powder consists of Egg-shells[1] and Snails,[2] both

[1] Egg-shells and Snails calcined in crucible surrounded with coal for 8 hours. Then left in earthenware pan to slake in a dry room for 2 months. The Shells thus become of a milder taste, and fall into powder.

[2] Snails left in crucible until they have done smoaking, then rubbed up in a mortar. Take 6 parts of Egg-shell to 1 of Snail-powder. Snails ought only to be prepared in *May*, June, July and August.


WILLIAM CULLEN, M.D.
PROFESSOR OF CHEMISTRY.

calcined. The decoction is made by boiling some Herbs[1] (together with a Ball, which consists of Soap,[2] Swines'-Cresses, burnt to a Blackness, and Honey) in water. The Pills consist of Snails calcined, Wild Carrot seeds, Burdock seeds, Ashen Keys, Hips and Hawes, all burnt to a Blackness, Soap and Honey."

Dr. Cullen and his colleagues held opposing views as to the efficacy of such quaint and caustic remedies; and it was with the object of discovering a "milder alkali," and bringing it into the service of medicine, that Black began his experiments on magnesia. They are described in a paper entitled "Experiments upon Magnesia Alba, Quicklime, and some other Alcaline Substances"; it was the chemical contents of his thesis for the degree of M.D., which he took at Edinburgh in 1754; he had been making the experiments since 1752. The actual thesis was in Latin: "De Humore Acido a Cibis orto, et Magnesia Alba"; the pamphlet was published in the following year.

The medicines in vogue as solvents of the urinary calculus were all caustic; the *lapis infernalis*, or caustic potash, and the ley of the soap-boilers, or caustic soda. These substances are made from mild alkali, or carbonates, by boiling their solutions with slaked lime, itself produced by slaking quicklime with water. Now quicklime is formed by heating lime-stone in the fire; it thereby acquires its burning properties, or causticity; and this it was supposed to derive from the fire, of which it absorbed, as it were, the essence. The act of

[1] Herbs of decoction: Green Chamomile, Sweet Fennel, Parsley, and Burdock; leaves or roots.

[2] Soap: Best Alicant Soap.

boiling the mild alkalies with lime was supposed to result in a transference of this educt of fire to the alkalies, which themselves became caustic. Lime-water, or a solution of caustic lime was used as a solvent for the calculus; and it was an attempt to produce a less caustic solvent from Epsom salts that induced Black to begin his researches.

As his notes show, Black began by holding the old view. He attempted to catch the igneous matter as it escaped from lime, as it becomes "mild" on exposure to the air: he appears to have made some experiment with this view; but his comment was: "Nothing escapes—the cup rises considerably by absorbing air." Two pages further on in his note-book he records an experiment to compare the loss of weight sustained by an ounce of chalk when it is calcined with its loss when dissolved in "spirit of salt," or hydrochloric acid; and he then evidently began to suspect the reason of "mildness" and "causticity."

Another memorandum, a few pages later, shows that he had solved the mystery. "When I precipitate lime by a common alkali there is no effervescence. The air quits the alkali for the lime, but it is not lime any longer, but c.c.c. It now effervesces, which good lime will not."

But we must trace the chain of reasoning which led him to come to this conclusion.

Having prepared "mild" magnesia by mixing Epsom salt or sulphate of magnesia with carbonate of potash, or "pearl-ashes," he found that it is "quickly dissolved with violent effervescence or explosion of air by the acids of vitriol, nitre, and of common salt, and by distilled vinegar"; that the properties of these salts—the

PROFESSOR BLACK LECTURING.
From John Kay's Caricatures.

sulphate, nitrate, chloride, and acetate of magnesium—differ greatly from those of the common alkaline earths; that when boiled with "salt-ammoniac," or chloride of ammonium, volatile crystals of smelling-salts were deposited on the neck of the retort, which, on mixing with the chloride of magnesium remaining in the retort, reproduced the "mild" magnesia; that a similar effect is produced by boiling "mild" magnesia with "any calcareous substance"; while the acid quits the calcareous salt to unite with the magnesia, "mild" magnesia is again precipitated on addition of a dissolved alkali.

On igniting "mild" magnesia, it changed into a white powder, which dissolved in acids without effervescence. And the process of ignition had deprived it of seven-twelfths of its weight. Black next turned his attention to the volatile part; he attempted to restore it by dissolving the magnesia in a sufficient quantity of "spirit of vitriol" or dilute sulphuric acid, and separated it again by the addition of alkali. The resulting white powder now effervesced violently with acids, and "recovered all those properties which it had lost by calcination. It had acquired besides an addition of weight nearly equal to what had been lost in the fire; and as it is found to effervesce with acids, part of the addition must certainly be air."

Black here made an enormous stride; he had weighed a gas in combination. He argues further: "It seems therefore evident that the air was forced from the alkali by the acid, and lodged itself in the magnesia." We may represent the change diagrammatically thus:

Magnesia ↘ ↗ Alkali → Vitriolated alkali.
Spirit of vitriol ↗ ↘ Air → Mild magnesia.

The next step was to try whether mild magnesia lost the same weight on being mixed with acid as it did when heated in the fire. But owing probably to the solubility of the fixed air in the water, a much less loss was found on dissolving the magnesia (35 grains out of 120) than by heating it (78 grains out of 120). The amount of acid required to expel the fixed air was, however, practically the same as that required to dissolve the *magnesia usta*, or heated magnesia (267 and 262 grains).

Turning his attention next to chalk, he dissolved some in muriatic acid, and having precipitated with fixed alkali no difference could be detected between the recovered and the original chalk. He had thus first separated the fixed air from the chalk, and then recombined the two. These experiments led Black to conclude that fixed air must be of the nature of an acid, for it converts quick-lime—the acrid earth, as he termed it—into crude lime, or mild earth, the mildness being due to its union with fixed air.

The explanation is thus given of the curious fact that mild magnesia, mixed with lime-water, gives pure water; for the fixed air leaves the magnesia and unites itself to the lime, and both the *magnesia usta* and the chalk which are formed are insoluble in water. And the action of quick-lime in causticising alkali is similarly explained by its removing the fixed air from the alkali, thus rendering the latter caustic, while itself becoming mild.

Reasoning further, Black foresaw that caustic alkali, added to Epsom salt or vitriolated magnesia, should give a precipitate of magnesia which should not effer-

Professor Black.
From John Kay's Caricatures.

vesce with acids, for here fixed air is excluded; and, also, that caustic alkali should separate from acids lime in the quick state, only united with water.

Similar experiments of treating chalk with acids and heating it, which had been performed with magnesia showed similar results.

But it had yet to be demonstrated that fixed air did not share the properties of ordinary atmospheric air. So Black placed four fluid ounces of lime-water, as well as four ounces of common water, under the receiver of an air-pump, and exhausted the air; air rose from each in about the same quantity; it therefore appeared that the air which quicklime attracts is of a different kind from that which is mixed with water. Quicklime does not attract air when in its most ordinary form, but is capable of being joined to one particular species only, "which is dispersed through the atmosphere, either in the state of a very subtle powder, or, more probably, in that of an elastic fluid. To this I have given the name of *fixed air*, and perhaps very improperly; but I thought it better to use a word already familiar in philosophy than to invent a new name, before we be more fully acquainted with the nature and properties of this substance."

The next step was to examine the nature of caustic alkali, and to prove whether it gained weight on being made "mild." This was achieved indirectly, by finding the amount of acid required to neutralise the same weight of caustic alkali, and "salt of tartar,"—what we know as potassium carbonate. Six measures of acid were required to saturate the former, and five the latter; and Black was very near the truth; indeed his error was

only about four per cent. He proved, by addition of sulphuric acid that the caustic alkali contained no lime, and therefore that its causticity was not due to an admixture of that substance.

To prove that lime-stone, or magnesia "loses its air" when dissolved in an acid, but regains it on addition of a mild alkali, the acid in which the lime was dissolved passing to the alkali, Black added caustic ley to a solution of Epsom salt, the result being a precipitate of magnesia; this dissolved in vitriol without effervescence, showing that no fixed air had taken part in the change. He also, on adding caustic alkali to a solution of chalk in spirit of salt (or hydrochloric acid) produced lime, which on being dissolved in water produced lime-water, indistinguishable from that produced from quicklime and water. He goes on to say that "had we a method of separating the fixed alkali from an acid, without at the same time saturating it with 'air' we should then obtain it in a caustic form." It can be done, it is true, by heating nitre with charcoal, but the alkali is then found saturated with air; and again by heating the alkali-salts of vegetable acids, the same occurs. Black conjectures that the fixed air must be derived either from the nitre or the charcoal in the first case (indeed it is derived from both, the nitre supplying the oxygen to the carbon); and in the second, he remarks that the vegetable acid is not really separated, but rather destroyed by the fire. How nearly he came to the discovery that fixed air is produced from carbon!

Such was Black's research on fixed air. And now having shown that a gas can be retained by a solid, and can be made to escape by treatment with acid or

by heat, he attacked somewhat later the problem of the cause of this fixation. He discovered it to be due to what he termed "latent" or hidden heat. But his research was not made with this object; the connection of the two was fortuitous, although of a fundamental nature.

Between the years 1759 and 1763, he formed opinions regarding the quantity of heat necessary to raise equally the temperatures of different substances. Boerhaave imagined that all equal portions of space contain equal amounts of heat, irrespective of the nature of the matter with which they are filled; and his reason for this statement was that the thermometer stands at the same height if placed in contact with objects near each other. Here we have a confusion between heat and temperature; and this was perceived by Black, for he pointed out that a distinction must be drawn between *quantity* and *intensity* of heat: the latter being what we now call *temperature*. He quotes Fahrenheit to show that while equal measures of water at different temperatures acquire a mean temperature when mixed, it requires three measures of quicksilver at a high temperature to convert two measures of water at a low temperature to the mean of the two temperatures; and this corresponds to twenty times the weight of the water. Black expressed this by the statement that the capacity for heat of quicksilver is much less than that of water.

But before this, in 1757, Black had made experiments leading up to these views. He had noticed that when ice or any solid substance is changing into a fluid, it receives a much greater amount of heat than what is perceptible in it immediately afterwards by the

thermometer. A great quantity of heat enters into it without making it perceptibly warmer. Conversely, in freezing water or any liquid, a large amount of heat comes out of it, which again is not revealed by a thermometer.

He then proceeded to estimate the quantity of heat which had to be absorbed by a known weight of ice in order to melt it. He hung up two globes side by side, about 18 inches apart, in a large empty hall, in which the temperature remained practically constant; each globe contained 5 ounces; one of ice at 32°F., the other water at 33°. The latter had a delicate thermometer suspended in it. The temperature of the hall was 47°F. In half an hour, the water had attained the temperature 40°F.; and the ice took ten hours and a half to attain the same temperature, that is, twenty-one times as long as the water. The heat, which the ice absorbed during melting was $(40-33) \times 21$ or 147 units; that is, had it been absorbed by the five ounces of water it would have made it warmer by 147°. The temperature of the ice, however, was 8° warmer than its melting-point, after the 21 half-hours; hence 139 or 140 "degrees had been absorbed by the melting ice, and were concealed in the water into which it had changed."

The method of experiment was next varied. Black weighed a lump of ice, and added it to a weighed quantity of warm water of which the temperature was known. The warm water was cooled to a much lower degree by the melting of the ice, than if it had been mixed with a quantity of water of 32°F., equal in weight to the ice. The quantity of heat absorbed by

the ice in melting, appeared from this second experiment to have been capable of heating an equal quantity of water through 143°F.

A third experiment was made, in which it was proved that a lump of ice, placed in an equal weight of water at 176°, lowered the temperature of the water to 32°. Now $176 - 32 = 144°$,—again a similar result. The latent heat of water is therefore about 142 or 143, in Fahrenheit units. The result of the most careful measurements give 79.5° centigrade units, which corresponds with 143° units of Fahrenheit's scale. Curiously enough, this fundamental datum has not yet been determined with the accuracy which it is customary now-a-days; and it is still uncertain to one sevenhundredth of its value. Black's determination was a remarkably good one, especially if we consider the crude appliances which he used.

The substance of this research was communicated to the "Philosophical Club," or society of Professors and others in this University in the year 1762; and was expounded yearly by Black in his lectures to his students.

Black suggested to Irvin, his pupil, and afterwards his successor in the Glasgow chair, to determine the latent heat of fusion of spermaceti and bees-wax; and he found that these substances, too, absorb heat, insensible to the thermometer, on assuming the liquid state. In this manner, he made his thesis general. But in attempting to extend it beyond the cases of liquids and solids, he went astray. For example, he imagined that the great rise of temperature, which may even reach redness, caused by the hammering of iron by a skilled

smith, was due to the "extrication of the latent heat of the iron by hammering." He did not realise that heat can be *produced* from mechanical work; that work can be quantitatively transformed into heat; a discovery made more than 80 years later, by Joule, although it had been anticipated by Count Rumford, and by Sir Humphry Davy, in the beginning of last century.

Similar experiments were made by Black on the latent heat of steam, in which he compared the time required for a known weight of water to rise through a definite interval of temperature when exposed to a constant supply of heat with that required to dissipate the water into steam. But his estimate of 830 units required to evaporate one part of water was not so accurate; the actual figure is 967 units on the Fahrenheit scale. Black cited experiments by Boyle, by Robison, his successor in the Glasgow chair, and by Cullen, his predecessor, in which the boiling point of liquids had been found to be lowered by reduction of pressure; he rightly ascribes this to the freer escape of the vapour, and to the absorption of heat by the vapour, and the consequent cooling of the liquid from which it is escaping.

These conceptions of Black's were utilised by his friend James Watt in his work on condensers, and, as everyone knows, effected a revolution in the structure of steam engines, and as a consequence in the whole of our industrial and social life; and further, they were developed by many men of science, until in the hands of the masters—Joule, Clerk-Maxwell, Rankine, James Thomson, and Kelvin, on the physical side, and of Willard Gibbs, the American, whose recent loss all men

of science deplore, on the chemical side—they form the very ground-work of the sister sciences, physics and chemistry.

Black's great chemical discovery that a gas exists which is clearly not a modification of atmospheric air, seeing it can be "fixed" by alkalies and alkaline earths, led the way to "pneumatic chemistry," as it was called, and was followed by the discovery of oxygen by Priestley, of nitrogen by Rutherford, of hydrogen by Cavendish and Watt, and of the more recent discoveries of argon and its congeners, all of them constituents of the atmosphere. In fact, the gases of the atmosphere have been discovered entirely by Scotsmen and Englishmen.[1]

And Black's proof, that the change of a complex compound to simpler compounds, and the building up of a complex compound from simpler ones can be followed successfully by the use of the balance, has had for its consequence the whole development of chemistry. It is only in the most recent years, since Becquerel observed the effect of uranium ores and salts in discharging an electroscope, and since Madame Curie discerned one of the causes of the discharge by uranium ore, namely, the existence in it of a new element, radium, and since Rutherford and Soddy's isolation of the gases evolved from radium and from thorium, that a new and more sensitive instrument has been placed at the disposal of chemists in the electroscope. We are at the beginning of a new era. Every discovery of a new principle of research heralds a new departure; and the

[1] In justice to the Swede, Schule, it should be said that his discovery of oxygen was contemporaneous with Priestley's.

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